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Performance of diesel engine using biodiesel obtained from mixed feedstocks

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ABSTRACT

Availability of identified tree species bearing non-edible oil has a region specific production characteristics and availability of sufficient amount at a given place is always uncertain. Moreover, the any prospective biodiesel production and utilization programe would need to consider more and one feedstock to meet the target. There could be another reason to investigate feasibility of mixed feedstocks considering strength and weakness of biodiesel fuel properties specific to feedstocks. Considering the above the present investigation is carried out to study the fuel characteristics of biodiesel obtain from mixed feedstocks of three species of oil feedstocks namely polonga, koroch and jatropha. An attempt has been made in this paper to give an overview of the application of mixed biodiesel in CI Engine. Properties of biodiesel obtained from mixed feedstocks (BOMF) satisfy different biodiesel standards. Performance of BOMF fueled engine gives better result than the individual biodiesels.

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1. Introduction

Biodiesel is produced by using virgin or used vegetable oil (both edible and non-edible) and animal fat through transesterification. Most of the biodiesel producing countries use edible oil seeds as feedstock, for example sunflower and rapeseed in Europe, soybean in the USA, palm oil in Malaysia, and coconut in Philippines. India has also justified reason to go for large scale production of biodiesel using domestic feedstock. But, India is not self sufficient in edible vegetable oil production. Possibilities of increasing vegetable oil production through extension of cultivated area are also limited. Therefore, India has focused on non-edible oil seeds feedstock for biodiesel production. Number of plant seed feedstocks is available in the country with favorable soil and climatic factors with distinguishing variations amongst different parts of the country. About ten numbers of plants are identified as chemically suitable feedstock in India [1]. However, these feedstocks varieties are at different levels of economic feasibility. These feedstocks differ in its physical and chemical characteristics. The option therefore left with the country is to consider non-edible oil seeds as feedstock for biodiesel production.

Out of these ten species [jatropha (*Jatropha curcas*), jojoba (*Simmondsia chinesis*), karanja (*Pongamia pinnata*), kusum (*Garcinia indica*), mahua (*Madhuca indica*), neem (*Azadirachta indica*), simarouba (*Simarouba glauca*), tung (*Aleurites species*), wild apricot (*Prunus armeniaca*), kukom (*Garcinia indica*)] are identified as economic potential for biodiesel production, which, jatropha and to a lesser extent karanja have received much attention.

Government of India has recently formulated a biofuel policy with an aim to supplement about 10% of diesel consumption through biodiesel by the end of 2016–2017 [2]. This will cause an annual requirement of 835 million tons (Mt) of biodiesel which will be far below the potential estimate of non-edible base biodiesel (100 Mt/yr) [3]. Thus, there is a need to enhance the biodiesel production.

Availability of identified tree species bearing non-edible oil (such as jatropha, jojoba, karanja, kusum, mahua, neem, simarouba, tung, wild apricot and kukom) have a region specific production characteristics and availability of sufficient amount at a given place is always uncertain. Moreover, any prospective biodiesel production and utilization programe would need to consider more and one feedstock to meet the target. There could be another reason to investigate feasibility of mixed feedstocks considering strength and weakness of biodiesel fuel properties specific to feedstocks. Considering the above the present investigation is carried out to study the fuel characteristics of biodiesel obtained from mixed feedstocks of three species of oil feedstocks namely polonga, koroch and jatropha.

2. Feedstocks description

Polanga tree grows in areas with 1000–5000 mm rain per year at altitudes from 0 to 200 m. It is a medium-sized tree, normally up to 25 m tall, occasionally reaching up to 35 m and with diameter up to 150 cm. The fruit is a round drupe, 2–4 cm in diameter. The single, large seed is surrounded by a shell (endocarp) and a thin, 3–5 mm layer of pulp. The fruit is at first pinkish-green later turning bright green and when ripe, it turns dark gray-brown and wrinkled. There are 100–200 seeds/kg. The tree can flower and bear fruit all year round in Indian conditions [4–6].

The middle-size, evergreen koroch tree with spreading branches are commonly available in Assam [7]. Wood of koroch is hard and heavy and yellowish in color. A fully mature tree produces up to 50 kg of seeds yearly with about 33.6% oil content. In addition to the dominant use of the koroch wood as cooking fuel, the seed and bark have traditional medicinal uses [7].

Jatropha curcas is a large soft wooded, deciduous, multipurpose tree of 47-m height, which belongs to the family Euphorbiaceae [8]. The wood and fruit of jatropha curcas can be used for numerous purposes including fuel. The seeds of jatropha curcas contain viscous oil, which can be used for manufacture of candles and soap, in cosmetics industry, as a diesel/paraffin substitute or extender. This latter use has important implications for meeting the demand for rural energy services and also exploring practical substitutes for fossil fuels to counter greenhouse gas accumulation in the atmosphere. These characteristics along with its versatility make it of vital importance to developing countries [9,10].The seeds contain about 30% oil.

3. Materials and methods

3.1. Feedstock

Oils of polonga seed, koroch seed and jatropha seed were collected from three different region of India namely Orissa, Assam and Rajasthan respectively primarily due to predominance of availability.

3.2. Transesterification

Two step transesterification processes was followed using methanol (Merck), sulfuric acid (Merck) for acid transesterification whereas methanol (Merck) and potassium hydroxide (KOH) for base transesterification process. Brief description of process is given below.

In a 5000 ml round bottom flask, about 900 ml mixed oil with 30% v/v of methanol to oil ratio and 0.5% v/v of sulfuric acid to oil ratio were taken for first step (acid catalyzed) transesterification. Mixture was stirred at a constant speed of 700 rpm and temperature was maintained at 50 °C. Free fatty acid (FFA) level was determined at 5 min interval for first 30 min and thereafter 30 min interval upto 1 h using potassium hydroxide (KOH) titration taking about 5 ml sample from reaction vessel. Acid catalyzed transesterification process was stopped when FFA was found to reduce upto 1%.

The sample of first step reaction was further reacted with KOH (base catalyst) adding methanol to maintain oil to methanol ratio 6:1. Reaction was repeated with sample of first step reaction (6 l) with methanol (1.3 l) and 60 g of KOH (base catalyst). Sample of first step reaction (6 l) with methanol (1.3 l) and 60 g of KOH (base catalyst) were stirred at a constant speed of 700 rpm and temperature was maintained at 70 °C. Reaction was conducted for 3 h and then mixture allowed settling down under gravity in a separating funnel. Upper layer was biodiesel which was washed with water and vacuum distilled to remove moisture.

4. Properties of biodiesel

Density (using digital densitometry, ASTM D 4052), kinematic viscosity (using U tube viscometer, ASTM D 445), flash point (using Pensky Martens apparatus, ASTM D 93), pour point and cloud point (ASTM D 97/2500), Copper Strip Corrosion property (ASTM D 130), and Calorific value (Bomb calorimeter, ASTM D 240) are determined at laboratories of the Indian Institute of Technology Delhi, India.

5. Testing of biodiesel for engine performance

Sample of biodiesel obtained from mixed feedstocks was used to prepare blends (20B, 40B, 60B, 80B, and 100B) so as to

investigate their performance in C I engine. Brief specification of engine was given in Table 1.

Engine was coupled to a 5 KVA electric generator having provision for load adjustment. Tests were conducted at six specific levels of load conditions. These are no load, 20%, 40%, 60%, 80%, and full load. Simultaneous measurement of engine speed (tachometer), fuel consumption (burete), exhaust gas temperature (thermocouple) and emissions of CO, HC, Smoke opacity(AVL make; model 4000 Di-Gas Analyzer and AVL make Smoke Meter, Model 437) were recorded (Fig. 1).

6. Results and discussion

6.1. Changes of fuel properties

Properties of biodiesel obtained from mixed feedstocks (BOMF) as well as polonga, koroch and jatropha (PB100, KB100 and JB100) biodiesels are tabulated below (Table 2).

6.2. Density

The density of biodiesel obtained from BOMF was found to be 870 kg/m^3, as compared to 879, 870 and 880 kg/m^3, for the polonga, koroch and jatropha biodiesels, respectively. Density for BOMF was lower than polonga and jatropha biodiesels but higher than koroch biodiesel. However, the densities of BOMF, polonga, koroch and jatropha biodiesels are satisfying the biodiesel standards of European Organization (EN 14214) and India (BIS IS15607).

Table 1
Engine specifications.

Make	Kirloskar
Model	DAF 8, four stroke diesel engine
Rated brake power (kW)	5.9
Rated speed (rpm)	1500
Number of cylinder	One
Bore X stroke (mm)	87.5 × 110
Displacement volume (cc)	779.70
Compression ratio	17.5:1
Cooling system	Air cooled
Lubrication system	Forced feed
Cubic capacity	0.78 Lit
Fuel Injection timing (degree)	26 BTDC
Injector opening pressure (bar)	200

6.3. Kinematic viscosity

As seen from Table 2, there has been change of the BOMF viscosity from individual biodiesel percentage of −5.3% for polonga, +14.28% for koroch and −0.83% for jatropha. Viscosity of BOMF falls within the range of viscosities of individual biodiesels. Viscosity is influenced by characteristics fatty acid profile of FAME. Thus biodiesel obtained from three different feedstocks namely polonga, koroch and jatropha resulted in viscosity well within the three biodiesel standards as shown in Table 2.

6.4. Calorific value

As seen from Table 2, there has been increase of calorific value of BOMF over koroch (7.63%) and polonga (0.21%). On the other hand, marginal decrease was noticed from the jatropha (1.16%).

6.5. Flash point

The BOMF has higher flash point (163 °C) as compared to polonga (143 °C), koroch (145 °C) and jatropha (135 °C) biodiesels. In terms of transport and handling, BOMF will provide advantage over the individual biodiesels [11]. It can be seen from Table 2 that Flash points of all biodiesels are well within the three biodiesel standards.

6.6. Pour point

It indicates the waxy nature of the oil. It also serves as a guide to its pumpability. It is observed from Table 2 that the pour point of BOMF decreases 33% in comparison to polonga biodiesels. But pour point of BOMF increases 66.66% in comparison to koroch. However, pour points of BOMF, polonga, koroch and jotropha biodiesels are within the prescribed limit of United States (ASTM D 6751) standard as seen from Table 2.

6.7. Cloud point

It is seen from Table 2 that the cloud point of BOMF decreases (43.4%) in comparison to polonga biodiesel but cloud point of BOMF increases (33.3% and 16.7%) in comparison to koroch and jotropha biodiesels. Though cloud point of BOMF is higher than koroch and jatropha biodiesels, the achieved result is of limited

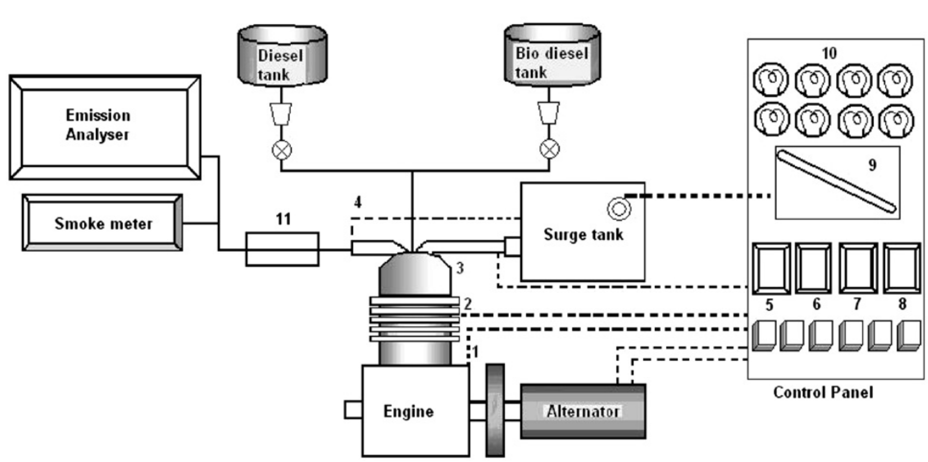


Fig. 1. Experimental test setup.

Table 2
Comparison of BOMF with polonga, koroch and jatropha biodiesel.

Property	BOMF	Polonga biodiesel (PB100)	Koroch biodiesel (KB100)	Jatropha biodiesel (JB100)	EN14104-2003	ASTM D 5761-02	BIS IS15607-2005
Density at 15 °C, kg/m^3	870	879	870	880	860–900	–	860–900
Kinematic viscosity at 40 °C, cSt	4.76	4.90	4.08	4.80	3.5–5.0	1.9–6.0	2.5–6.0
Calorific value, (MJ/Kg)	38.67	38.59	35.72	39.12	–	–	–
Flash point (°C)	163	143	145	135	> 120	> 130	≥ 120
Pour point (°C)	3	4.5	1	3	–	−15 to 10	–
Cloud point (°C)	6	10.6	4	5	–	−3 to 12	–
Copper strip corrosion at 50 °C, for 3 h	No. 1	No. 1	No. 1	No. 1	Class 1	No. 3 max.	No. 1

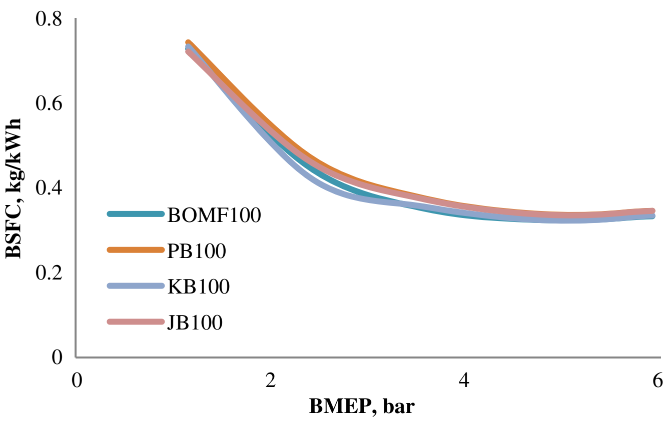


Fig. 2. Brake specific energy consumption for different biodiesels.

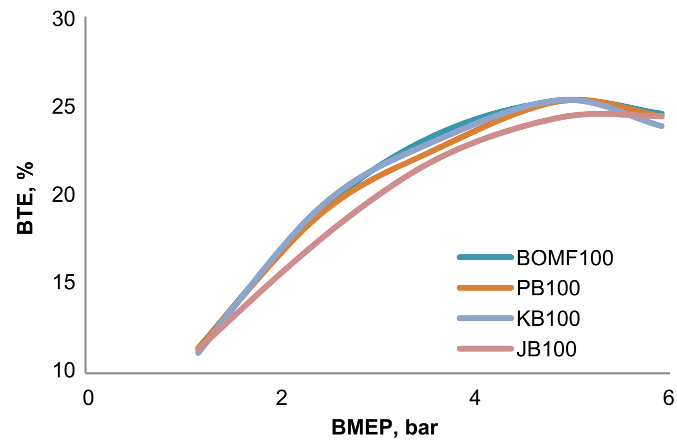


Fig. 3. Brake thermal efficiency for different biodiesels.

concern in the temperate climate of Asia. The cloud points of BOMF, polonga, koroch and jotropha biodiesels are within the limit of United States (ASTM D 6751) standard.

6.8. Copper strip corrosion

This test gives an indication of the corrosiveness of the fuel to the metallic parts of the system in which the product is used, whether during transportation or actual use in engine. Results reveal that all copper strips obtained for BOMF as well as polonga, koroch and jatropha biodiesels showed a classification code of 1, which indicates slight tarnish, almost the same as the freshly polished strip. These results indicate that BOMF as well as polonga, koroch and jatropha biodiesels would not cause corrosion. Copper Strip Corrosion of BOMF and polonga, koroch and jatropha biodiesels satisfies the three biodiesel standards.

7. Engine performance and emissions

Engine performance of BOMF was compared with the engine performance of biodiesels obtained from individual feedstocks (polonga, koroch and jatropha biodiesels). Two series of experiments were conducted viz (a) with no blending of mineral diesel (BOMF, PB100, KB100 and JB100) (b) with 20% biodiesel blending (BOMF20, PB20, KB20 and JB20).

7.1. (a) With no blending

Fig. 2 shows the brake specific fuel consumption (BSFC) variation for the BOMF with polonga, koroch and jatropha biodiesels (PB100, KB100 and JB100). As the load increases, BSFC for all fuels decreases. BSFC for BOMF is 2.06% lower than PB100, 0.72% lower than KB100 and 0.91% higher than JB100 at no load. BSFC for BOMF is 3.65% lower than PB100, 0.51% lower than KB100 and 3.64% lower than JB100 at full load. Densities of PB100 and JB100 are more than BOMF. Increasing density may increase BSFC because the fuel injector injects a constant volume, but larger mass, of more dense fuel. Calorific value of KB100 is much lower than BOMF. Increase of BSFC of KB100 than BOMF may be attributed to lower calorific value.

Fig. 3 shows that thermal efficiency of engine is higher for BOMF than PB100, KB100 and JB100 for all loads. Thermal efficiencies of the engine using BOMF are 0.61%, 2.81% and 0.53% higher than PB100, KB100 and JB100 at full load. Brake thermal efficiency decreases with increase in density. PB100 and JB100 have higher densities than BOMF. Similarly, Brake thermal efficiency decreases with decrease in calorific value. Brake thermal efficiency of KB 100 may be lower due to its lower calorific value than BOMF. Brake thermal efficiency of KB 100 may be lower due to its high percentage of unsaturation in fatty acid composition.

Fig. 4 shows the variation of exhaust gas temperature (EGT) with load. The result shows that the EGT increases with increase in load for all the cases. Exhaust gas temperatures (EGT) of PB100, KB100 and JB100 are 1.54%, 1.16% and 0.97% higher than BOMF at full load. Similarly, EGT of PB100, KB100 and JB100 are 22.81%, 2.22% and 30.68% higher than BOMF at no load. EGT is an indication of how hot the combustion process is in the cylinders, and the amount of "afterburning" that is occurring in the exhaust manifold. EGT is also directly related to the air/fuel ratio. The richer the air/fuel ratio in a diesel, the higher the EGT will be.

It is seen from Fig. 5 that HC emissions are 13.33%, 7.14% and 10.34% lower for BOMF than PB100, KB100 and JB100 at full load. The chain length of the compounds had greater influence on HC emissions. HC was reduced with decreasing chain length.

The CO emissions are found to increase with increase in load (Fig. 6). This is typical with all internal combustion engines since

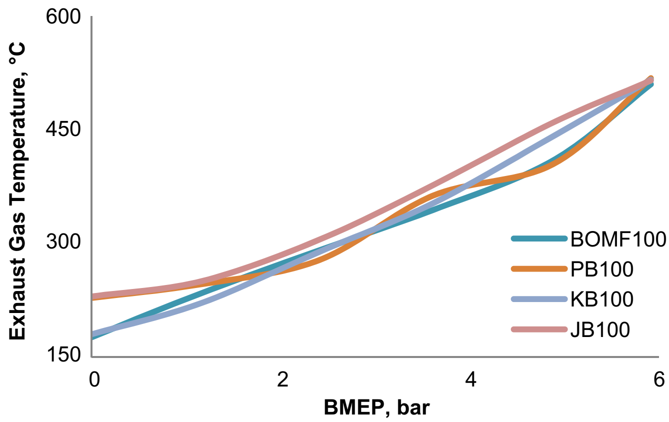


Fig. 4. Exhaust temperature for different biodiesels.

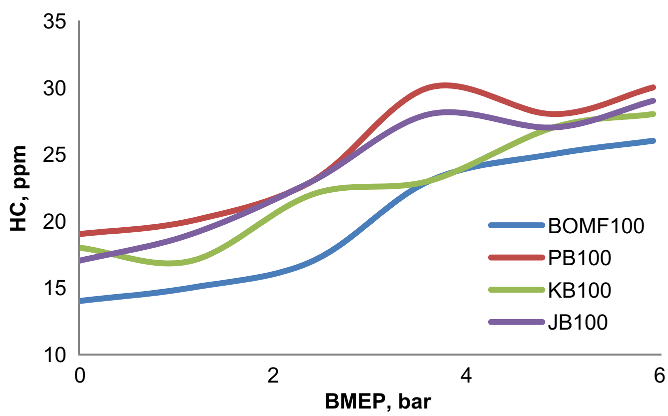


Fig. 5. UBHC emission for different biodiesels.

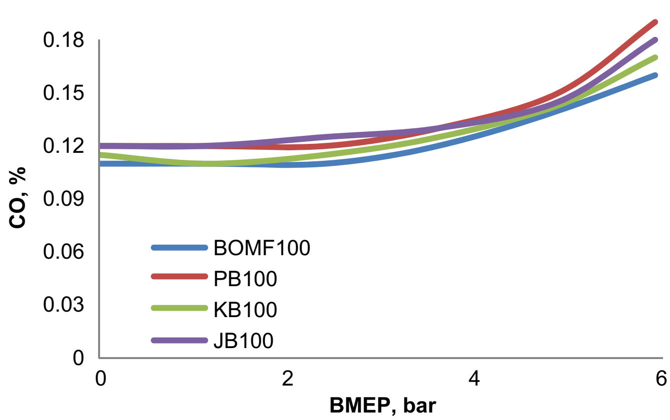


Fig. 6. CO emission for different biodiesels.

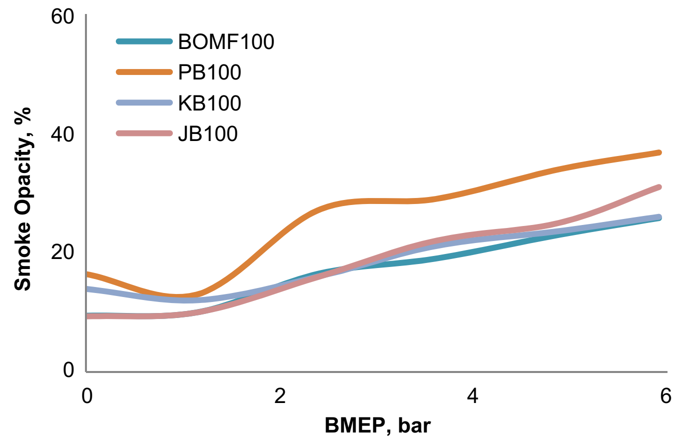


Fig. 7. Smoke opacity for different biodiesels.

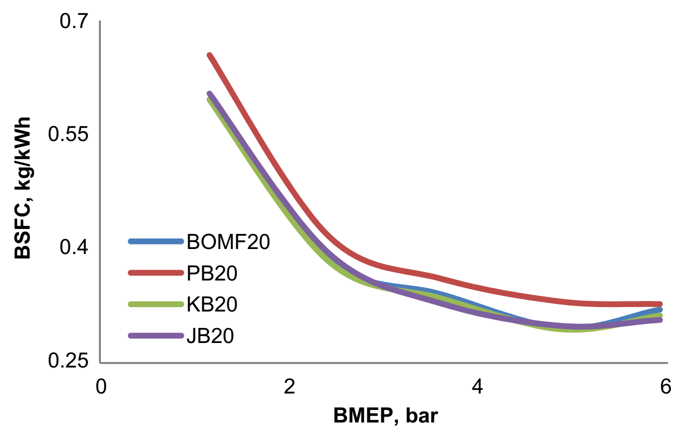


Fig. 8. Brake specific energy consumption for different biodiesel blends.

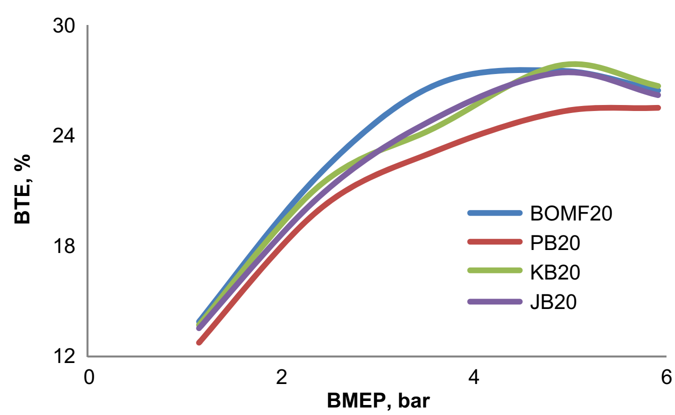


Fig. 9. Brake thermal efficiency for different biodiesel blends.

the air-fuel ratio decreases with increase in load. The CO emissions are 15.79%, 5.88% and 11.11% lower for BOMF than PB100, KB100 and JB100 at full load.

Smoke opacity of PB100 is found to be highest in comparison to BOMF (Fig. 7). Smoke opacities of PB100, KB100 and JB100 are 29.89%, 0.77%, 16.77% higher than BOMF at full load.

7.2. (b) With 20% blending

Fig. 8 shows the brake specific fuel consumption (BSFC) variation for the BOMF blend (BOMF20) with polonga, koroch and jatropha biodiesel blends (PB20, KB20 and JB20). As the load increases, BSFC for all fuels decreases. BSFC of BOMF20 is 2.24% lower than PB20 and 4.25% and 2.44% higher than KB20 and JB20 at full load.

Fig. 9 shows that thermal efficiencies of the engine with BOMF20 is 3.57%, 0.96% and 0.92% higher than PB20, KB20 and JB20 at full load (Fig. 10).

The result shows that the exhaust gas temperatures (EGT) increases with increase in load for all the cases. EGT of PB20, KB20 and JB20 are 7.37%, 3.73% and 5.33% higher than BOMF20 at full load.

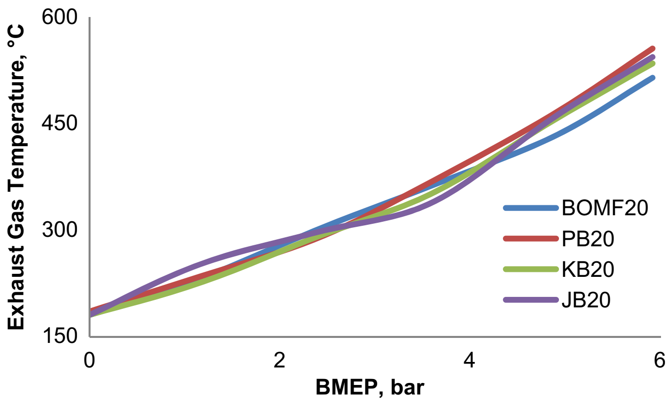


Fig. 10. Exhaust temperature for different biodiesel blends.

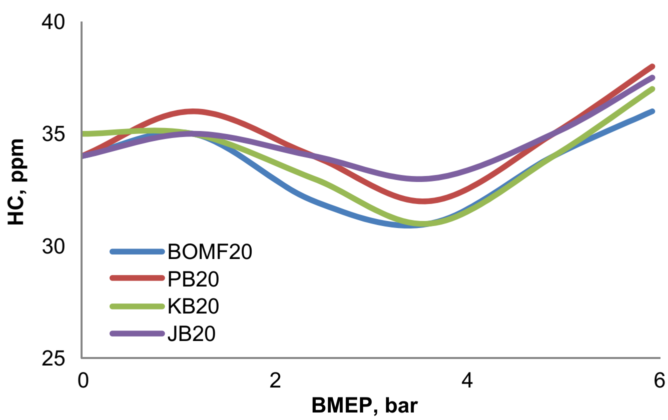


Fig. 11. UBHC emission for different biodiesel blends.

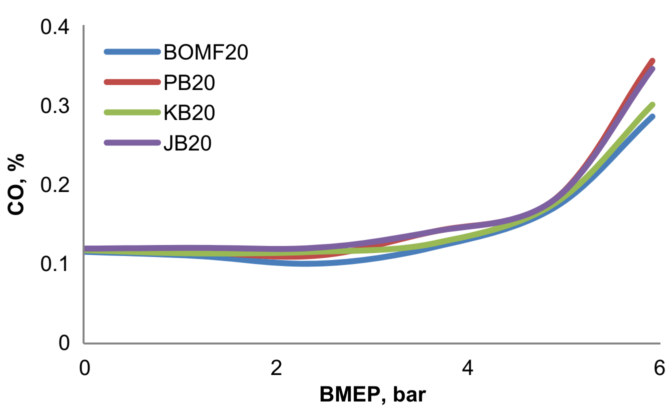


Fig. 12. CO emission for different biodiesel blends.

It is noticed from Fig. 11 that BOMF20 has 5.26%, 2.70% and 4.0% lower HC emissions than PB20, KB20, and JB20.

In case of blend fuels, CO emission is found lowest for BOMF20. Similarly, CO emission is highest for PB20. It is observed from Fig. 12 that BOMF20 has 19.72%, 5.0% and 17.39% lower CO emissions than PB20, KB20, and JB20.

In case of blend fuels, smoke emission is found to be lowest for BOMF20 (Fig. 13). It is monitored from Fig. 13 that BOMF20 has

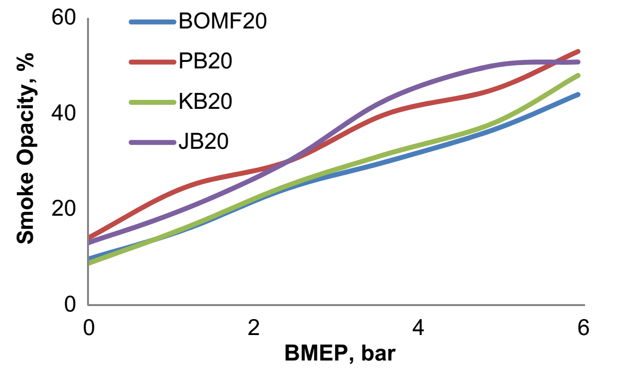


Fig. 13. Smoke opacity for different biodiesel blends.

16.98%, 8.33% and 13.39% lower smoke emissions than PB20, KB20, and JB20.

8. Conclusion

Properties of biodiesel obtained from mixed feedstocks (BOMF) and individual biodiesels (PB100, KB100 and JB100) satisfy different biodiesel standards namely European Organization (EN 14214), United States (ASTM D 6751) and India (BIS IS15607). BOMF shows improvement in terms of physical properties than the individual biodiesels. In terms of transport and handling, BOMF provides advantage over the individual biodiesels.

Performance of BOMF fueled engine gives better result than the individual biodiesels. BSFC for BOMF is 3.65% lower than PB100, 0.51% lower than KB100 and 3.64% lower than JB100 at full load. Thermal efficiencies of the engine using BOMF are 0.61%, 2.81% and 0.53% higher than PB100, KB100 and JB100 at full load. Also, BOMF shows the better result in terms of exhaust emissions (CO, HC and smoke) than the individual biodiesels. Similarly BOMF20 fueled engine reflects better result in term of performance and emissions that PB20, KB20 and JB20.

Existing design of diesel engine doesn't need any substantial modification for using BOMF as fuel.

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